BY ADRIAN WEISS, WØRSP

THE ART OF VERY LOW POWER OPERATING

Your First Homebrew QRP Rig—The TWOFER

The October 1987 QRP column provided background on the genesis of the QRP-ARCI club project during the QRP bash at the 1986 Dayton Hamvention. As you may recall, the G-QRPC had come across the pond with a stock of "ONER" simple transistor transmitter kits which sold out almost immediately. The QRP-ARCI then decided to design its own simple transmitter, market it in kit form, and sponsor a QRP Homebrew Contest to emphasize homebrewing in this country.

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The "TWOFER" plus Homebrew Contest strategy is aimed at enticing all you appliance types into taking the big step of building an easy, "guaranteed to work right off the bat" transmitter with a guaranteed opportunity to work other QRPers operating similar rigs. Fantastic idea! In one stroke we eliminated the two major deterrents to homebrewing, judging from my mail and chats with many QRP and non-QRP operators.

The first problem in homebrewing is parts acquisition. All components for just about any project *can* be obtained via mail order, but you have to know *where* to find parts. Providing a complete kit solves that problem. Many homebrewers have then complained that once they go through the frustrating process of waiting for ordered parts, they finally toss together a rig in a couple of hours and then can't find any QRPers to work with the thing. The winter and summer Homebrew Contests solve that problem. In addition, the QRP nets listed in the QRP column for January 1988 on page 75 provide the opportunity to work other QRPers on four days of each and every week throughout the year. I've had several cards from fellows who gave the nets a try as a result of that column, and they worked a bunch of QRPers. The bottom line is if you've been reluctant to jump into homebrewing because of those two problems

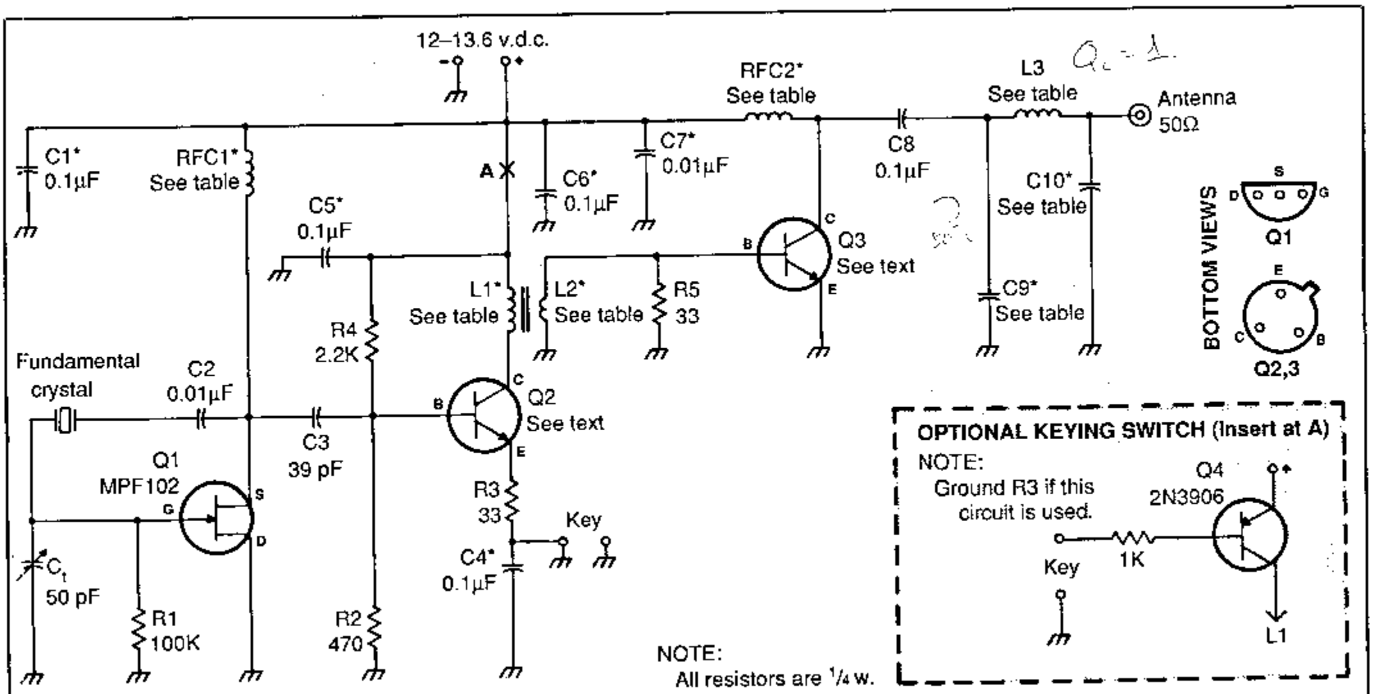


Table for L1-2-3 and C9-10

Band	L1*	L2	C9 & C10	L3
80	43t	2.5t	750 pF	21t
40	35t	2.5t	470 pF	14t
20	27t	2t	220 pF	12t
15/10	17t	1.5t	100 pF	9t

**L1-2, L3 are wound on T-50-2 Amidon Toroid cores (t denotes number of turns).*

L1: #26 enameled copper; L2: plastic-covered hook-up wire; L3: #24 enameled copper. Available at Radio Shack, or Belden #8052 and #8053.

C9-10: Silver mica or dipped tantalum.

RFC1: 13t #28 on Amidon FB-73-801 "jumbo bead"; or 36t #28 on Amidon FT-37-43 toroid; or 500 uH Radio Shack RF choke.

RFC2: 13t #28 on Amidon FB-73-801 "jumbo bead"; or 24t #24 on FT-37-61 toroid; or 25 uH 1 amp Radio Shack RF choke.

Parts Notes

A complete kit (including PCB, T-50-2's, FB-73-801's, transistors, and all other parts) is available from The Small Parts Center, 6818 Meese Dr., Lansing, MI 48911, for $9.95. Ct is extra (Millen 50 pF variable $4.50, or ARCO 404 trimmer $1.40). Or, capacitors, resistors, and transistors can be ordered from:

Circuit Specialists, P.O. Box 3047, Scottsdale, AZ 85257;

Digi-Key, Inc., P.O. Box 677, Thief River Falls, MN 56701;

MPJ: Marlin P. Jones & Assoc., P.O. Box 12685, Lake Park, FL 33403-0685 (305-848-8236);

Mouser Electronics, 2401 Hwy 287 North, Mansfield, TX 76063 (817-483-4422);

BCD Electronics, P.O. Box 830119, Richardson, TX 75083-0119;

Order crystals from JAN Crystals, P.O. Box 06017, Ft. Meyers, FL 33906-6017.

Order T-50-2, FT-37-43, FT-37-61 toroids, FB-73-801 "jumbo beads" from Amidon Associates, Inc., 12033 Otsego, N. Hollywood, CA 91607, and BCD.

Order Ct small variable capacitor (50–100 pF) from BCD, and Marlin P. Jones.

Fig. 1– Schematic of the TWOFER, including a table for L1-2-3 and C9-10.

in the past, there isn't any excuse now!

As with all group projects, it took longer than expected to implement these ideas than was originally expected. But everything is in place now. John Collins, KN1H, designed the "TWOFER" transmitter with an assist from Mike Michaels, W3TS, by October 1986, about four months behind schedule. The kit concept was "market tested" at the 1987 QRP gathering at Dayton and was a stunning success. Most of the 20 kits offered by Fred Turpin, K6MDJ, and Bob Speidel, W6SKQ, of the Zuni-Loop Mountain Expeditionary Force were sold before the QRP-ARCI had a chance to set up its booth. Quite a few guys were miffed because they didn't have a chance to buy one. Talk about a hot item!

The club went forward full-throttle and gave Bill Harding, K4AHK, hard-working treasurer and subscriptions manager, the job of acquiring parts for about 100 kits. Bill had done it as of January 1988, and they're ready for shipment! By the time this appears they might be gone, so it would be a good idea to check first before ordering from John Collins, RR2 Box 427, Cornish, NH 03745 ($22.50 postpaid, not including crystal). However, the availability of club kits is no problem. The Small Parts Center—operated by Chris Hethorn, KM8X, a veteran QRP homebrewer who decided to solve his own and every homebrewer's parts problems by marketing a complete selection—has put together a complete kit (not including crystal) for the TWOFER version featured in this article (including PC board) for $9.95 postpaid (see details in the parts notes section of fig. 1).

Since the implementation of the TWOFER kit phase of the project took so long, activity in the first Winter Homebrew Sprint didn't benefit from the potential existence of at least 120 homebrew rigs which could have been on the air. Moreover, the Sprint was announced too late to be included in this column. Even so, there was an opening burst of activity on December 12, 1987 for about the first hour of the four hour sprint lasting from 2000–2400 UTC. Results are not yet in, but a few scattered comments have surfaced.

Bob Brown, NM7M, reports that "The Homebrew Sprint started with a bang but tailed off here in about 90 minutes. I worked 23 QRPers, about half of them with homebrew gear, but after 2130 UTC, I just ran out of people to work." Wes Hayward, W7ZOI, notes that "It turned out to be a really great event. I made 27 contacts on 40, 20, and 15 meters, and of the 27, twelve sent 'HB' [homebrew] as part of the exchange. Guess that's to be expected." Rich Arland, K7YHA, QRP columnist for *World Radio*, didn't comment on the number of QRPers worked, but noted that he had just put up a 4BTV vertical with three radials and accumulated "some interesting data" comparing it with a G5RV during the sprint, which saw a QSO with an NL7 in Alaska first on the list! He must have worked enough stations to come up with the data.

I was on with 1.5 watts output from a homebrew miniature 20 meter transceiver which has traveled to England several times, and I worked a lot of U.S. DX courtesy of G4BUE's fantastic 4-element Yagi. I worked eight QRPers in the first hour, but added only five more during the remaining three hours of on-off listening. Now if all those TWOFER kits had been on, all would have had to push hard to work everyone! There would have been no end to the list! So let's all get to work on a rig for the summer Homebrew Sprint scheduled for July 10, 1988, from 2000–2400 UTC! Get a kit, or follow the route discussed in the remainder of this article—build your own from scratch.

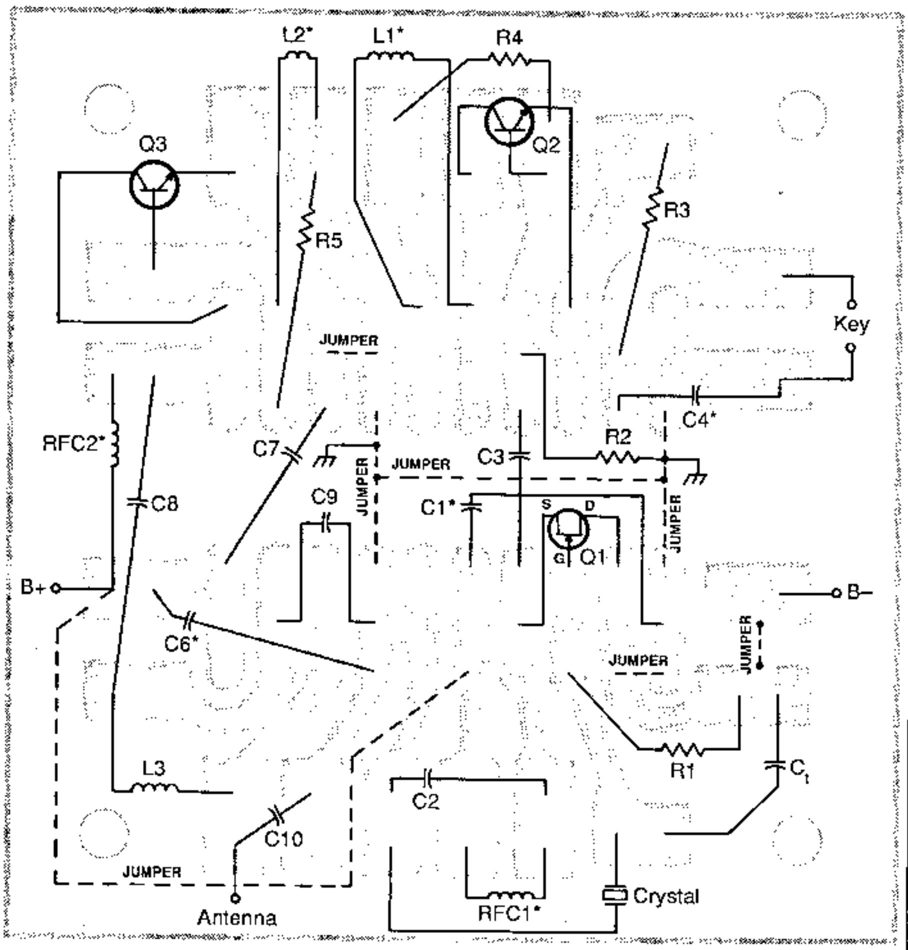


Fig. 2– PC board template and overlay.

The TWOFER

The credit for the TWOFER design goes to John Collins, KN1H, with assistance from Mike Michaels, W3TS, and they did a good job! I literally haywired my version on a Radio Shack 20-pin dual-in-line PC board. I ignored all my previous experience with homebrewing, dismissing usual considerations such as ground loops, perfectly wound toroids, etc. The only problem I encountered was caused by a "pulled" MPF102 FET at Q1. It was "dead," which is why it had been pulled from a previous circuit in the first place. Once I plugged in a good device, the oscillator took off and drove the buffer-amplifier stages to a healthy output. Photos of the haywire and compact second version are shown along with the circuit in fig. 1 and the PC board overlay is shown in fig. 2. I was impressed with the fact that the circuit worked right off with a whole passel of NPN transistors pulled from old computer PC boards. The only critical components are the inductors at L1-2 and L3, and the only care that need be taken is to put the specified number of turns on the toroid. The circuit is simple and foolproof. KN1H discussed it in "Build the TWOFER" in the October 1986 issue of the *QRP Quarterly*, and we'll extract relevant comments.

Oscillator. With respect to the Pierce crystal oscillator stage, KN1H noted: "The advantage of the Pierce oscillator, besides its obvious simplicity, is its lack of parallel capacitance. This means that the variable capacitor on the gate of Q1 wil vary the oscillator frequency from about 4 kHz on 80 meters to 15 kHz on 20 and 15 meters." The oscillator works on the crystal's fundamental frequency, and "crystal type is noncritical—every one of my junk box crystals worked fine." I had the same results. In addition, I tried several third overtone crystals for 15 meters and found that they worked on 40 meters, their fundamental frequency. Also, HC7/U and FT243 types both worked equally well.

VXO Circuit. The addition of the tuning capacitor Ct across the gate of Q1 transforms the circuit into a VXO or variable frequency crystal oscillator. As Ct is increased, the crystal is loaded and oscillates at a lower frequency. Given the downward shift in frequency produced by Ct, choose a crystal frequency so that the center of the spread is on a QRP calling frequency (i.e., 3560, 7040, 14060, 21060, and 28060 kHz). Hence, a choice of 7042 kHz for 40 meters will permit swinging 2 kHz above and below the center of activity. While a 50 pF capacitor is specified, I used a 100 pF variable to produce additional "rubbering," but not much more than the spread noted by KN1H. The addition of Ct has a second effect in that it creates an RF path between gate and ground which permits additional RF current to flow into the gate, thereby increasing the output from Q1. This effect occurs at about 15 pF and a downward shift of about 1 kHz on 40 meters. The difference in RF voltages and output at the high (minimum capacitance at Ct) and low ends of the VXO frequency range in my two units is shown in fig. 1. I should note that the leads to Ct are frequency sensitive. They should be stiff and firmly anchored; otherwise, any vibration or jostling will cause the frequency to jump. Similarly, RFC1 should be mounted solidly; a soldering iron can be used to melt any kind of candle wax onto RFC1 and the PC board to "wax" it in place.

RF Chokes. KN1H noted that the "values of the two RF chokes are not especially critical. For the oscillator choke (RFC1) I tried several values from 100 uH to 1 mH and all worked satisfactorily." In addition to standard Radio Shack units, he wound his own from 36 turns (#28 wire) on an Amidon FT-37-43 powdered iron toroid core. I took him at his word and tried several chokes of unknown value, and all worked. The purpose of the RF choke is to isolate the Q1 source from any RF on the B+ line. One trick (if no scope is on hand) to see if this is happening is to shunt a 1 mF or so capacitor across C1. No change in oscillator frequency will occur if the choke is doing its job. I ended up using 13 turns of #28 wire on an Amidon FT-73-801 powdered iron "jumbo bead" core. The 73-mix exhibits an mu of 2500, and 13 turns produces a quite large inductive value. For RFC2, KN1H used 24 turns of #24 wire on an FT-37-61 core. I went with the same value as used in RFC1. If a Radio Shack choke is used at RFC2, it should be rated at 1 amp or more to avoid DC loss in the amplifier circuit.

Driver. The Q2 driver stage is a simple Class A amplifier with link coupling to the base of Q3. With respect to the value of C3, KN1H noted: "Output from the oscillator is dependent on crystal activity, and the 39 pF coupling capacitor was chosen to limit transmitter output to 1.5 watts using my most active 80 meter crystal. As designed, power output is 1.2 watts on 40 meters, 1.1 watts on 20 meters, and 650 mw on 15 meters." My versions showed similar outputs, although the transistors tried at Q2 and Q3 produced considerable variations. The biasing resistor values given by KN1H were optimum with the 2N2219, 2N2222, and 2N2224 transistors. However, other common NPNs produced lower outputs. For example, the RMS voltages developed across R5 with a single-turn L2 link ranged from 0.22 volts RMS to 0.95 volts RMS for the following devices listed from low to high value: 2N697, 2N3053, 2N706, 2N2102, 2N3553, and 2N3642, with the '2200 series (2N2219, 2N2222, and 2N2224) giving the high value of 0.95 (B+ of 13.6 VDC). Resistor values could be changed experimentally to optimize the circuit for other transistors, but the wide availability of the last three types makes such an effort extraneous. Interestingly, one in-house marked Motorola "pull" put out 1.17 volts RMS.

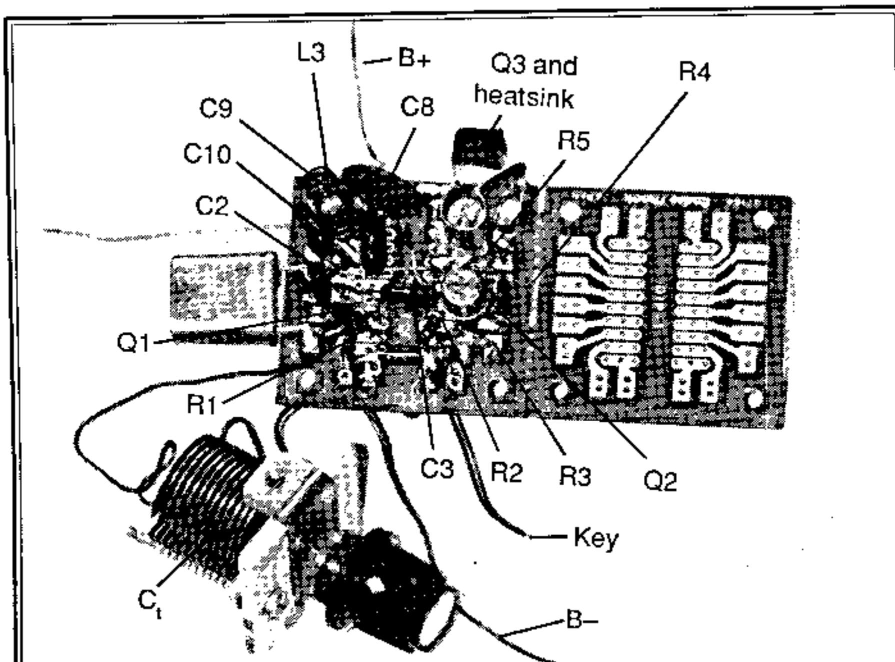
I made one significant change in the Q2 driver circuit by eliminating the keying switch transistor Q4 and using simple emitter keying. Fewer parts, and there's no decided advantage in using the keying switch (it is shown in the schematic in case you prefer to use it). The values for L1-2 are shown in the table with fig. 1. The L1 tank circuit does not include a tuning capacitance. The internal collector-emitter capacitance of Q2 serves the purpose. The L2 link of about 2½ turns of plastic-covered hook-up wire is positioned at about the mid-point of the L1 winding, away from the high-impedance end of L1. Don't attempt to increase drive power by adding turns to L2.

Amplifier. The amplifier stage at Q3 is a standard Class C type connected to the antenna through a pi-net output filter. R5 at once provides a fixed resistive load for Q2 in parallel with the dynamic base-emitter junction RF resistance while establishing a fixed DC bias point for Q3, thereby enhancing stability. KN1H recommended using NPN RF transistors such as the 2N3137, 2N3866, and 2N3553 at Q3, and cautioned: "Be careful not to overdrive a 2N3866 or other UHF transistor in the PA. They will give about 5 watts out for a few seconds and then open up. The reasons are their very high gain, especially at 80 meters, and the very close tolerances in the transistor—the very qualities that make them so good at UHF. The 2N3553 is probably the most reliable choice, as it will survive pretty outrageous SWR for those who like to tune-up for hours on end." My 2N3866 showed lower output than either the '2200 series or the 2N3553. It might be a dud that was roasted in another circuit, since it was a "pull." The 2N3553 will cost several dollars and produce more output than the cheapie "22" series. For example, on 40 meters with the B+ at 13.6 VDC and an L2 of 2½ turns, the 2N2224 showed a maximum of 1.4 watts into 50 ohms, while the 2N3553 put out 1.8 watts. The difference isn't worth $3.00 to me and won't make any difference on the air.

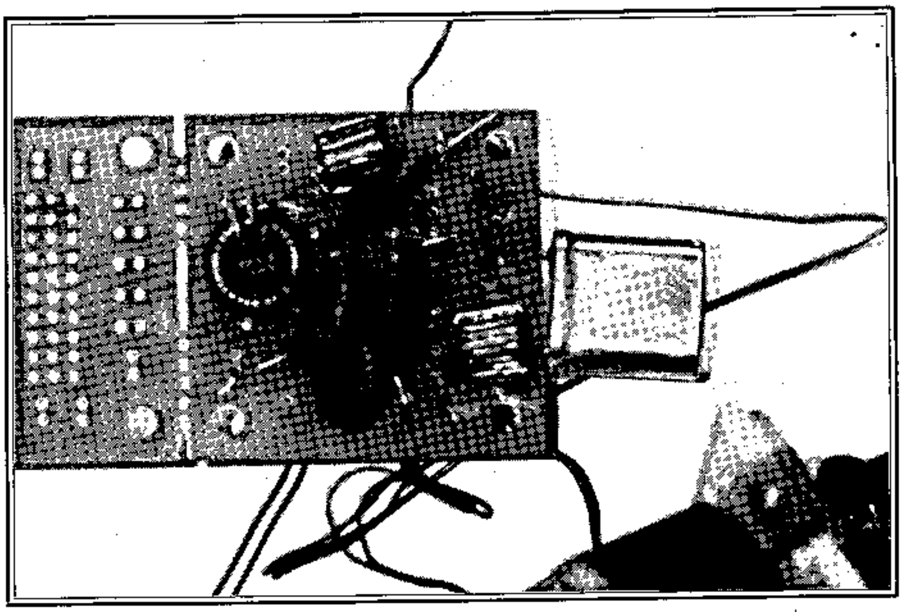
With respect to heatsinking the final amplifier transistor, this is not really necessary unless, as KN1H put it, you like to tune-up for hours on end. There really is no need for that! It took a half-minute of key-down operation at maximum output for the 2N2224 to begin to heat up noticeably. To stay on the safe side, a standard slip-on TO-5 heatsink could be used, or a homebrew sink made from thin copper or aluminum "shim stock" or flashing will do the job (see photo). Simply cut a ¼" × 1" or so piece of material and then wrap the middle of the strip around the transistor case and crimp tightly. The remaining material can then be bent to form two vertical fins. Finally, the output pi-net filter values (L3, C9, and C10) should be followed closely. The cut-off frequency of the low-pass filter is slightly above the frequency band and designed for 50 ohm terminations, which corresponds well with the collector load impedances for power outputs in the range obtained with the TWOFER. Increasing or decreasing the number or spacing of turns will produce a variation in output, but this should not be misinterpreted as an improvement in efficiency, etc. It usually indicates an introduction of distortion onto the signal waveform. If you'd like to learn more about building and adjusting a simple transmitter like this, a detailed discussion about circuit functions, debugging, and test procedures can be found in *The Joy of QRP* (available from *CQ*'s Bookshop).

Construction of the TWOFER

The only critical aspect of construction consists of making correct connections. Beyond that, the components can be mounted (or unmounted as in the "ugly construction" approach!) in any configuration. I've always found that PC boards make life simpler. The ready-made 20-pin double-in-line boards available at Radio Shack were first brought to my attention by NØARQ (see his versionof my HW-8 RIT circuit in *CQ*, May 1982, pp. 98–99, also included in the reprints of my HW-8 modification series). One glance convinced me that the approach was a real "winner," and I've been using these boards for working up circuits ever since! There must be a million holes and a whole bunch of pads on these things so that



The amplifier fills the top half of the Radio Shack #276-159 PC board with (left to right) C9-L3-C10-C8 to the left of Q3, which uses a heatsink as described in the text. Driver Q2 is below Q3, while Q1 is at the bottom left corner beside the crystal, which is soldered directly to the proper pads. One-quarter watt resistors are flush against the PC board and soldered directly to the pads. The B+ lead is at the top, antenna lead at the left, and B– and key leads at the bottom to the right of tuning capacitor Ct.



View of underside. Clockwise from bottom of crystal: RFC1, C1, C4, C5, L1-2, RFC2, and C6-7.

haywiring a circuit is a cinch.

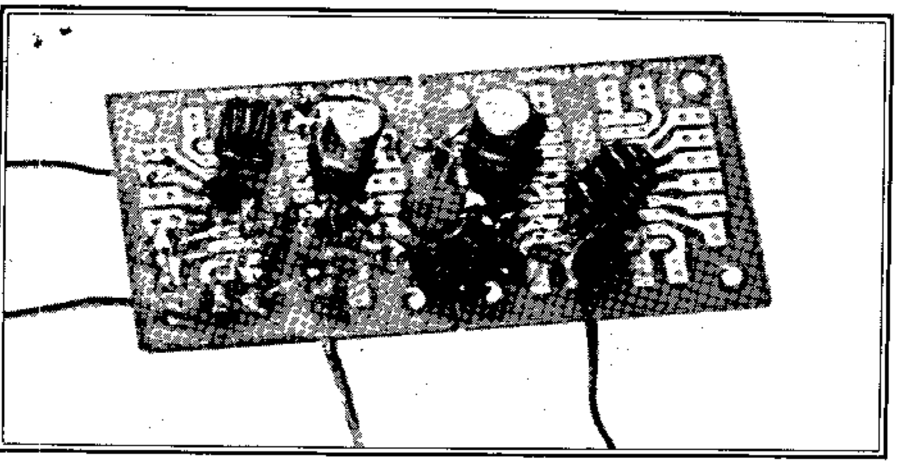
My first version of the TWOFER grew across two boards (they come in twos with holes for easy splitting apart). Then I decided to try to put the whole TWOFER on a single board, and that took a bit of planning. The final wiring configuration is shown in fig. 2. Each pad has five holes, permitting mounting components either foilside or underside. *Underside components are marked with an asterisk in figs. 1 and 2.* For foilside parts, the wire leads are inserted only far enough to leave some bare wire for soldering to the pads. Actually, there is no need to use the holes, since leads can be soldered directly to the pads. My decision to mount most of the parts on the foilside was based on the fact that it is easier to keep track of connections that way, since there are so many holes on the board. Circuit ground is established by joining several pads with jumper wires.

The unit is quite compact, as seen in the photos. Overall cubic size could be decreased considerably by using dipped tantulum or monolithic-chip by-pass capacitors at C1-2-4-5-6-7-8, and dipped tantulums or match-head caps at C3-9-10. I used standard silver micas and ½ inch ceramic discs in my units and the layout in fig. 2 so that there would be enough room if you don't want to order subminiature components. A second way of decreasing size (and reducing cost) is to substitute an ARCO 404 4-60 pF subminiature trimmer capacitor for the regular variable seen in the photos. The 404 leads can be bent into a right angle about ⅛ inch from the end to permit direct mounting across the bottom edge of the PC board of fig. 2. In this approach it will be necessary to use a screwdriver to shift frequency. However, this is only a minor inconvenience, since the tuning ratio is very broad and accurate zeroing is possible. Or, you can use a trick that I discovered in 1955 for creating a shaft when none exists. Find a hollow tube that fits onto the adjusting screw, and then expoxy it to the screw. The fit need not be exact, since the epoxy will make up the difference. Ballpoint pens are perfect. For example, the top end of a regular "Papermate" ballpoint fits snugly around the screw. It's a natural for this application. Finally, the HC7/U crystal is soldered directly to the PC board (see photo), although it could be socket-mounted on the enclosure. I plan to put mine into a Band-Aid box and use a socket.

The TWOFER kit offered by The Small Parts Center includes the above options for miniaturing the version shown here. Instead of disk ceramics, monolithic chips are provided for the by-pass and coupling capacitors. Hence, these can be mounted on the foilside of the board with a slight modification of the connections seen in fig. 2. For example, C6 and C7 can both be connected to the pads shown for C7. C1 and C4 are connected as shown, but C1 is moved to the left of Q1. RFC1 can be moved to foilside in a vertical stance. A mono-chip C8 will create space for foilside mounting of RFC2. Finally, L1-2 can be mounted in a vertical stance beside Q2.

A few other notes about The Small Parts Center kit will be helpful in ordering. First, specify the band to be used so that the correct values of C9-10 are provided. Second, the kit includes a MPF102, a 2N2222A, and a 2SC799, a 5 watt CB duplicate of the 2N3553 which costs just 55 cents (vs. $2.15) and provides the same higher output. A crystal socket, RCA phono jack for the antenna, wire for winding the chokes and coils, and the Radio Shack #276-159 PC board are included. Ct is optional. A high-quality Millen 50 pF unit will cost an extra $4.50, while an ARCO 404 4-60 pF trimmer is $1.40 extra. All you'll need is a crystal, soldering iron, pliers, and wire-cutters. A 12 volt (or a pair of 6 volt) lantern battery will provide power (almost) indefinitely.

As seen in the photo, the dual-in-line PC boards come in pairs with a series of holes on the boundary for easy snapping apart. I left the extra board attached for the eventual addition of a VFO. To drive the transmitter with a VFO, simply remove the crystal, connect the VFO output across the Q1 gate and ground, and commence operation. An ideal choice for this function is the VFO described in detail in *The Joy of QRP*. Another use for the extra PC board is suggested in KN1H's article in which he describes a simple direct-conversion receiver to go with the transmitter (hence the "two fer



Original version of my TWOFER spread across three columns of pads on the PC board beginning with Q1 at the left. The transistors are mounted in sockets to permit comparing several without the need for resoldering leads. Layout is not critical, and this approach will produce the same results as the compact layout shown in fig. 2.

one" monicker), and it could be mounted on the extra PC board as well. Actually, I may end up doing this instead of a VFO, since the VXO feature permits moving around the band a bit.

One drawback of these simple transmitter designs is that they will operate only on the band for which the crystal, L1-2, L3, and C9-10 have been selected. However, there is a relatively simple way around this which I haven't seen mentioned in the literature for transistor transmitters, although this method was the "bread-n-butter" of multiband operation in vacuum days. Obviously, I'm speaking of using p ug-in coils! Note that C9-L3-C10 form a lumped circuit with three terminals (input, output, and ground). It just so happens that transistor sockets also have three terminals. The light goes on . . . . Instead of soldering the output filter directly onto the PC board, a garden-variety low-profile PC-mounting transistor socket takes its place. Next, a method for plugging the lumped circuit into the socket has to be devised. You simply can solder C9-L3-C10 together, leaving leads that will fit the socket holes, but this is really clumsy. I cut a small piece of PCB stock large enough to mount the components and gouge two channels in the copper foil, which leaves three isolated pads for mounting the components. Three leads are also soldered to the proper pads and bent to fit the socket. Presto! The same approach can be taken for L1-2, but in this case a 4-pin transistor socket must be used.

There are quite a few possible variations on this approach, limited only by the almost infinite number of sockets available at a flea market! Dual-in-line sockets and plugs are a "natural" combination for this approach, since the components can be soldered directly to the plug terminals, thereby eliminating the need for making a PCB mount. The extra PC board in my unit, for example, could be used to mount a 16- or 20-pin dual-in-line socket. This would permit using standard silver micas for C9-10 and T-50-2 toroids for L1-2 and L3 with some space to spare. By shifting to dipped tantalum capacitors and T-30-2 toroids, an 8-pin DIP socket should be large enough to accommodate L1-2, L3, and C9-10. In either case, it might be possible to mount the remaining parts of the transmitter on the pads and holes around the periphery of the socket on a single board, assuming that dipped tantalum or mono-chip by-pass capacitors are used. The obvious advantage of the DIP plug-in is that only one is needed to shift both driver and final to another band.

At any rate, the use of this approach converts a single-band simple transmitter to a multiband unit. Change crystals, plug in the appropriate lumped circuits, and try another band! Since this is such a fantastic idea, a veritable child of inventive genius, it surely deserves more publicity than this one-shot offering. Therefore, I invite you all to try your hand at coming up with your unique variation of the plug-in lumped circuit idea. Send in a description of your innovation, specifying the exact (more or less) sockets/plugs you used, the source for these, and a drawing if that will make things clearer. We'll share them all in some future column. After all, if NØARQ hadn't had the brilliant idea of using the Radio Shack DIP PC board and taken the time to send it in, a lot of us would still be dinking around with isolated pads and haywiring!

The QRP ARCI Homebrew Sprints

Now to the fun of working QRPers with the TWOFER! Two events are scheduled for 1988. On July 10, 1988 from 2000–2400 UTC the Summer Homebrew Sprint can be entered using either homebrew or commercial equipment. However, the Winter Homebrew Sprint on December 11 (2000–2400 UTC) is limited to stations using either a homebrew transmitter, receiver, or transceiver. The exchange for QSOs includes RST, State/Province/Country, and QRP ARCI Member Number or power output if you are not a member. You can join the QRP ARCI by applying to: Bill Harding, K4AHK, 10923 Carters Oak Way, Burke, VA 22015, including $11 check/MO. This fee includes four issues of the *QRP Quarterly* as well as a membership number. In addition to the two Homebrew Sprints, bonus points are awarded in both Spring and Fall QSO Parties for the use of homebrew gear: +200 for each band with HB transmitter; +300 per band for HB receiver; +500 per band for HB transceiver. See the *QRP Quarterly* or *CQ*'s "Contest Calendar" for full details on scoring and rules.

Well, gang, that's the story on the TWOFER and Homebrew Sprints. The rig is easy to build and guaranteed to work. Why even think about it? Just go for it!

73, Ade, WØRSP